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Assessment of the interference risks in the 8025 – 8400 MHz frequency band

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CNES/DCT/RF/TT



1. Context

- X-band problematic
- Study objectives

2. Computation of the interference risks

- Theory
- Outputs

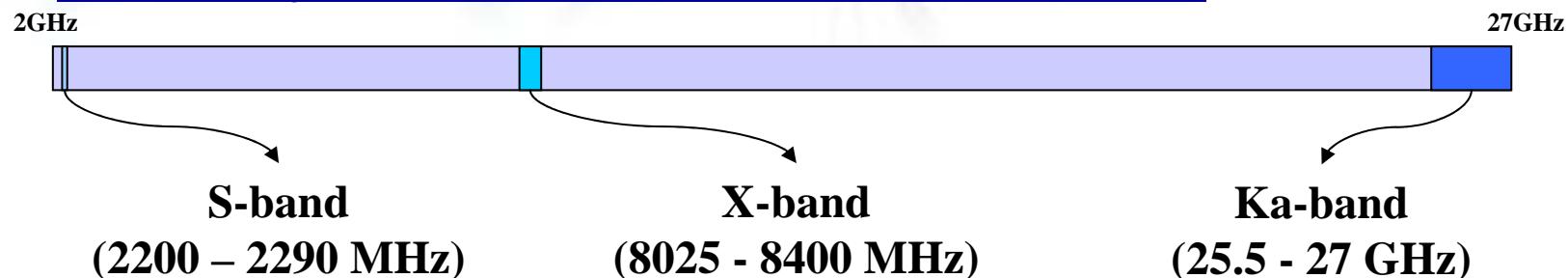
3. Simulation results

- Main interference sources
- Current and future interference risks
- Mitigation techniques

4. Conclusion

Context

Frequency bands allocated to science services



Used for platform telemetry

Can be used for payload telemetry at low data rates

Used for payload telemetry

30 missions are using this band today

30 new missions are planning to use this band in the next decade

Allocated during WRC 2000

High propagation impairments
immature technologies

Envisat – Artemis (ESA)
Ka Transposition Project (NASA)

Context

- ⇒ Use of the 8025 – 8400 MHz band : Problematic
 - Number of satellites ↑
 - Data rates ↑
 - ⇒ How to limit the interference risks ?
 - Migrate to the Ka-band
 - Operational coordination
 - Use more efficiently the frequency resources
 - ◆ Orbit choice
 - ◆ RF design
- } Interference risks between systems ↑

Context

- ⇒ RR. Article 21 : limit the power density to be transmitted in the band

$$\left\{ \begin{array}{ll} -150 dBW/m^2/4kHz & \theta \leq 5^\circ \\ -150 + \frac{\theta-5}{2} dBW/m^2/4kHz & \text{for } \theta \in [5^\circ, 25^\circ] \\ -140 dBW/m^2/4kHz & \theta \geq 25^\circ \end{array} \right.$$

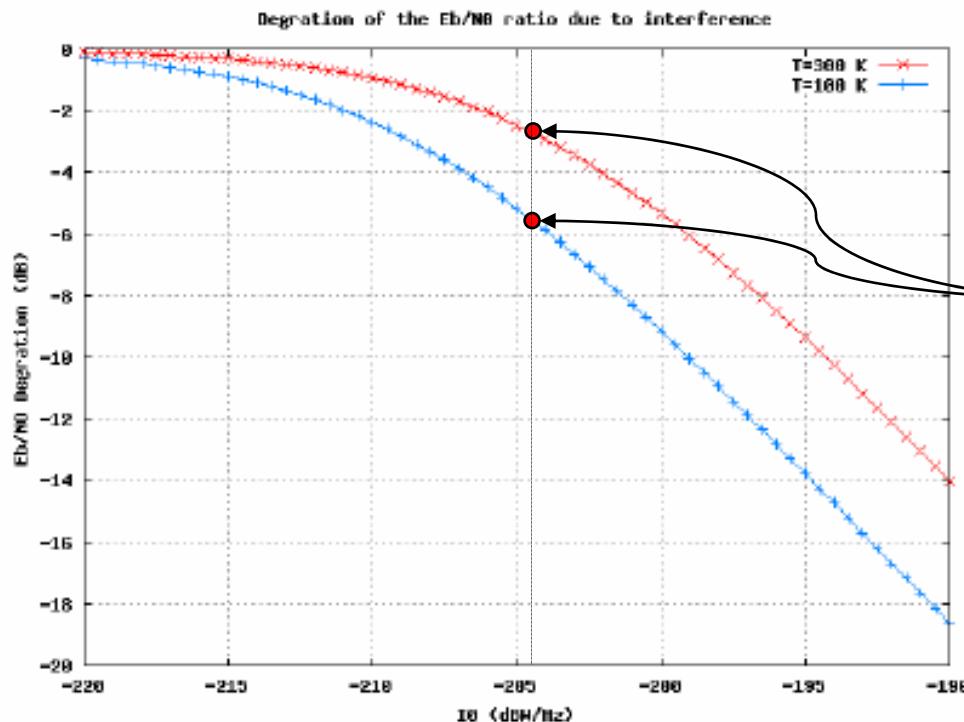
- ⇒ ITU-R SA 1026-3 Rec. : limit the signal power acceptable by services in a given band and during a given percentage of time

Type of earth station	Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than 20% of the time	Interfering signal power (dBW) in the reference bandwidth to be exceeded no more than $p\%$ of the time
55.2 dBic (9 m) Recorded data acquisition	$P(I_0 > -204.5 \text{ dBW/Hz}) = 1 \%$	
42.5 dBic (3 m) Direct data readout (System A)	$P(I_0 > -204.5 \text{ dBW/Hz}) = 1 \%$	
56.3 dBic (10 m) Direct data readout (System B)	$P(I_0 > -195 \text{ dBW/Hz}) = 1 \%$	

Context

⇒ Working toward a new criteria

$$\Delta \frac{E_b}{N_0} = \left(\frac{C}{N_0} \right)_{dB} - \left(\frac{C}{N_0 + I_O} \right)_{dB} = 10 \log_{10} \left(1 + \frac{I_O}{N_0} \right)$$

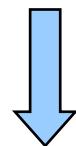


Important degradation
of the transmission link
performances

Context

Several studies have been performed in CNES and others space agencies in the framework of the space frequency coordination group (SFCG)

- Does a real risk exist today ?
- Will it increase in the next years ?
- What are the main interference sources ?
- How to evaluate the techniques to mitigate and limit the interference risks ?



Simulation



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3. Simulation results

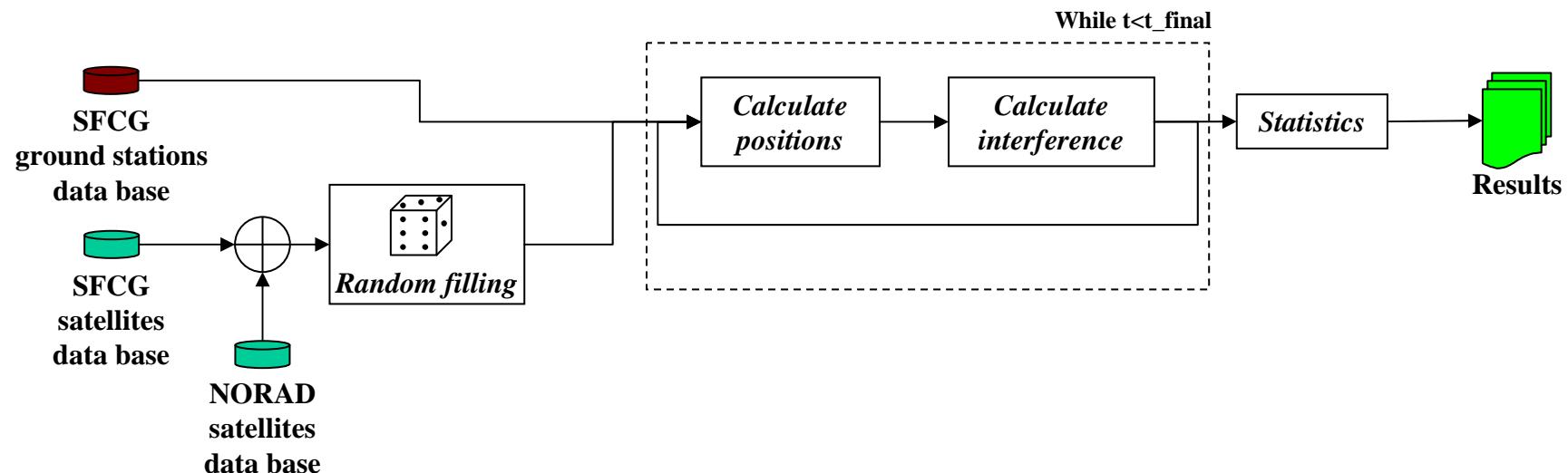
- Main interference sources
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Computation of the interference risks

Overview :

- ⇒ Choose a victim mission
- ⇒ Choose a victim Earth station



Computation of the interference risks

Location of the satellites and ground stations :

Satellites:

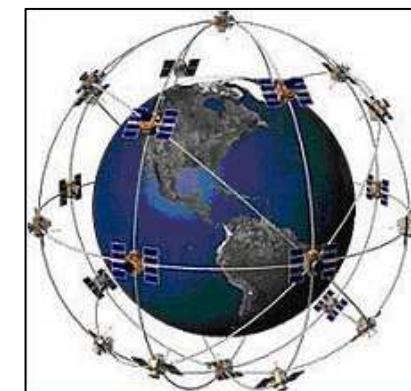
$$(a, e, M, \omega, i, \Omega) \longrightarrow (x, y, z)$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} \cos(\Omega) & -\sin(\Omega) & 0 \\ \sin(\Omega) & \cos(\Omega) & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(i) & -\sin(i) \\ 0 & \sin(i) & \cos(i) \end{pmatrix} \cdot \begin{pmatrix} \cos(\omega) & -\sin(\omega) & 0 \\ \sin(\omega) & \cos(\omega) & 0 \\ 0 & 0 & 1 \end{pmatrix} \cdot \begin{pmatrix} a \cdot (\cos(E) - e) \\ a \cdot \sqrt{(1 - e^2)} \sin(E) \\ 0 \end{pmatrix}$$

Earth stations:

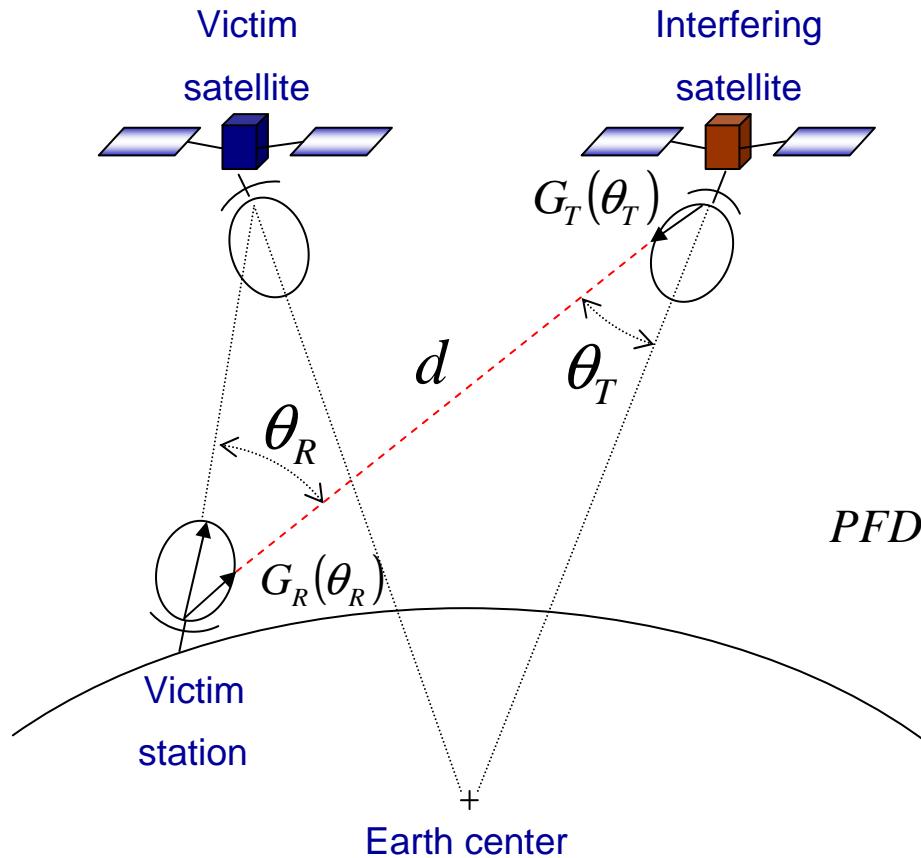
$$(\varphi, \lambda, h) \longrightarrow (x, y, z)$$

$$\begin{pmatrix} x \\ y \\ z \end{pmatrix} = \begin{pmatrix} (R_T + h) \cos(\varphi) \cos(\lambda) \\ (R_T + h) \cos(\varphi) \sin(\lambda) \\ (R_T (1 - e^2) + h) \sin(\lambda) \end{pmatrix}$$



Computation of the interference risks

Power of the interfering signals :



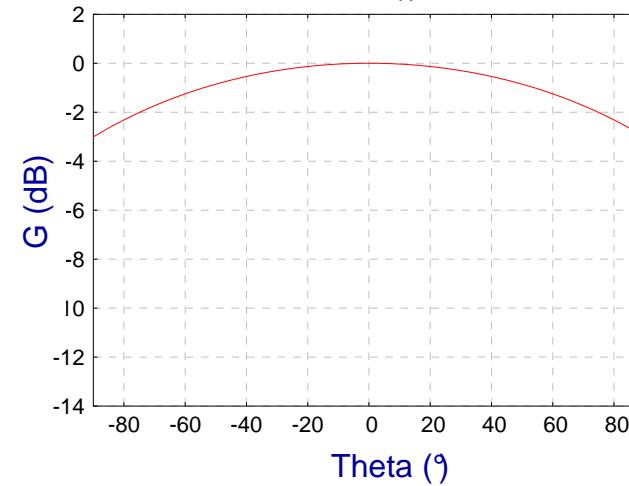
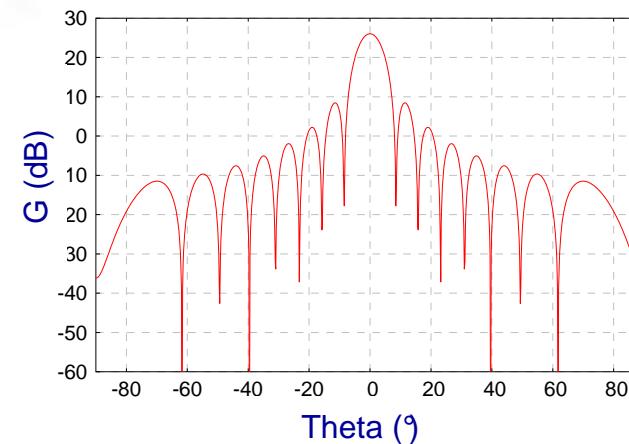
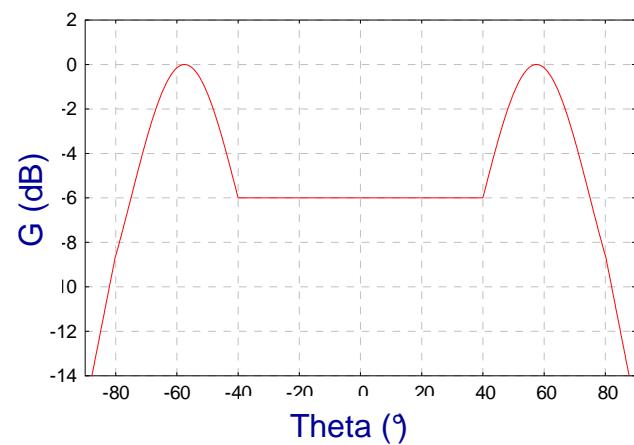
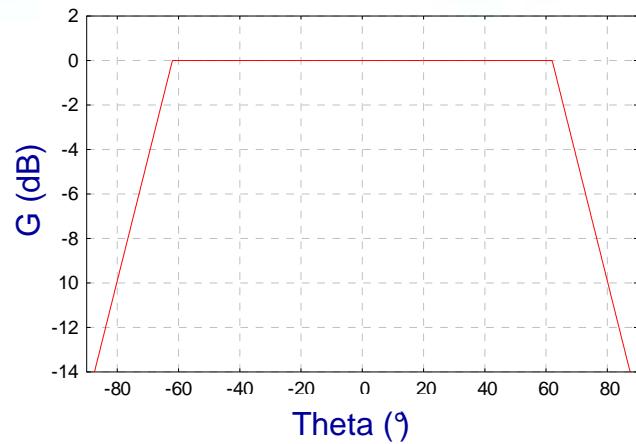
$$I = A_{ISO} \sum_{\substack{i=1 \\ i \neq j}}^n PFD_i(\theta_{Ti}, d_i) G_{Ri}(\theta_{Ri})$$

$$PFD(\theta_T, d) = EIRP + G_T(\theta_T) - 10 \log_{10}(4\pi d^2)$$

$$A_{iso} = \frac{\lambda^2}{4\pi}$$

Computation of the interference risks

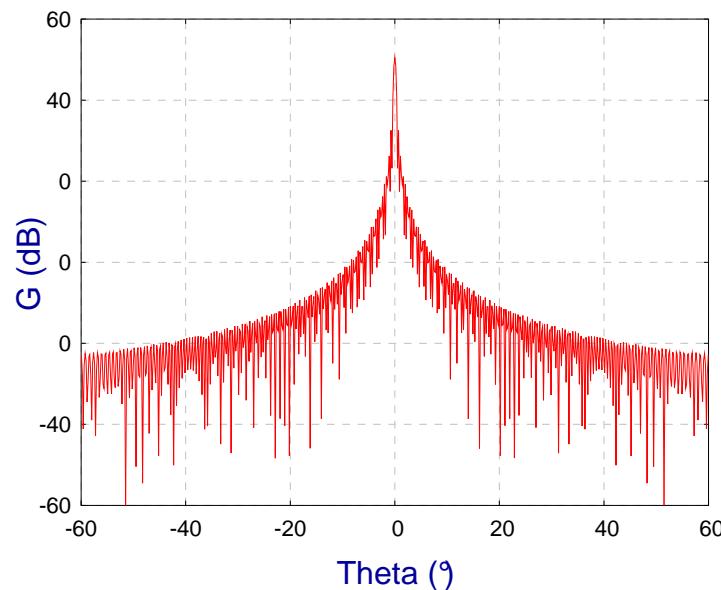
On board antenna pattern



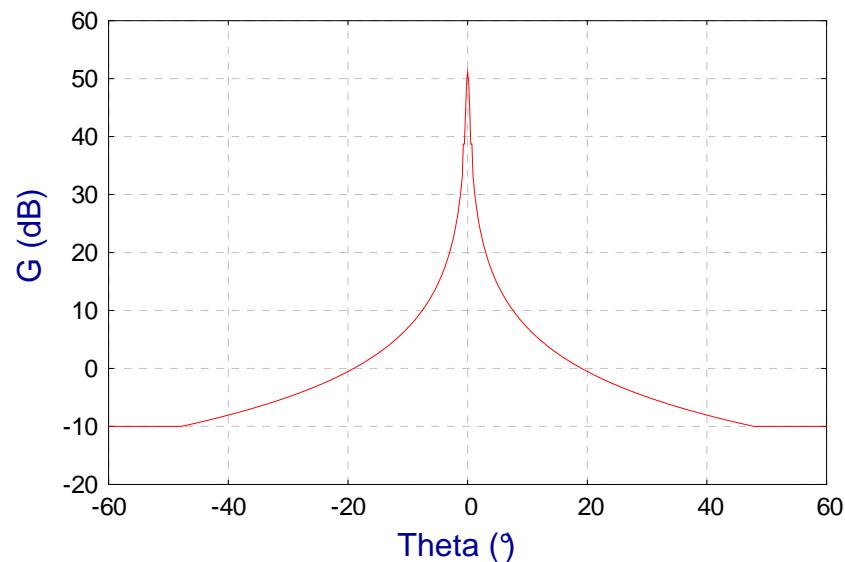
Computation of the interference risks

Earth station antenna pattern

Bessel function ($D = 5$ m)

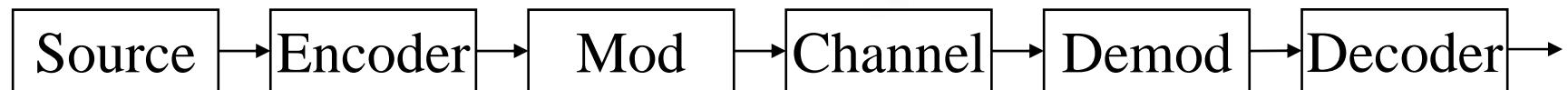


Annex III of appendix 8 of RR ($D = 5.4$ m)



Computation of the interference risks

Modulation and coding techniques



New modulation and coding techniques have been standardized.
(higher power/spectral efficiency)

Two modulations equivalent in term of band occupation for a given
data rate (1.867 bits/channel symbol) :

- ⇒ OQPSK with a Reed-Solomon encoder RS(255,239), $E_b/N_0 = 8$ dB
- ⇒ 4D 8PSK-TCM with a Reed-Solomon encoder RS(255,239)
 $E_b/N_0 = 5.2$ dB

Computation of the interference risks

Outputs to be considered :

- Number of crossings per day
 - Time percentage of transmission for the victim satellite
 - Time percentage of transmission affected by an interfering signal
 - Statistic distribution of the number of satellites in visibility
 - Statistic distribution of the number of interfering satellites
 - Maximum interference level for a 0.025% of time
 - Maximum interference level for a 0.25% of time
 - Maximum interference level for a 20% of time
- } to be compared to
ITU-R SA 1026-3
Rec.



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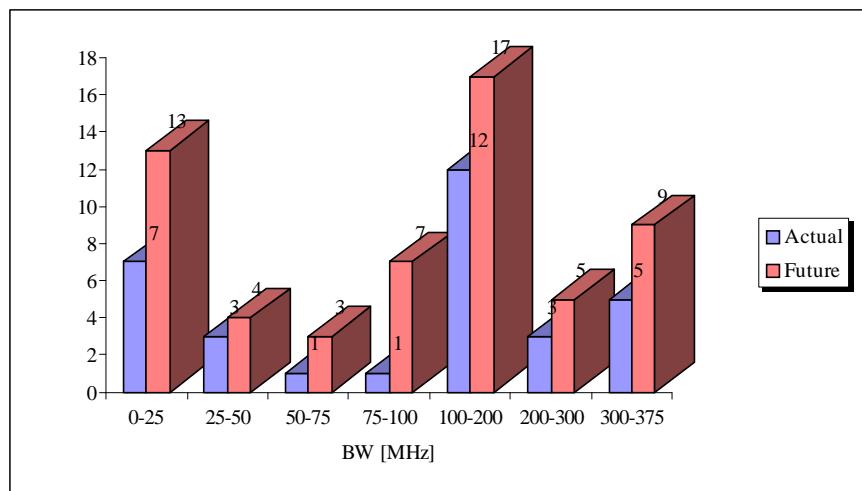
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Simulation results

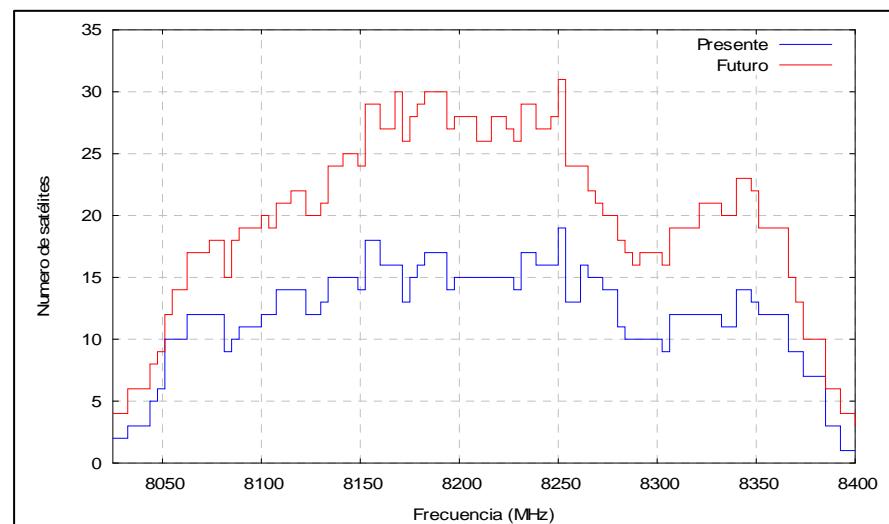
8025 – 8400 MHz band occupation

- 32 missions today \Rightarrow 58 missions in the future



There are more and more satellites that use the whole band

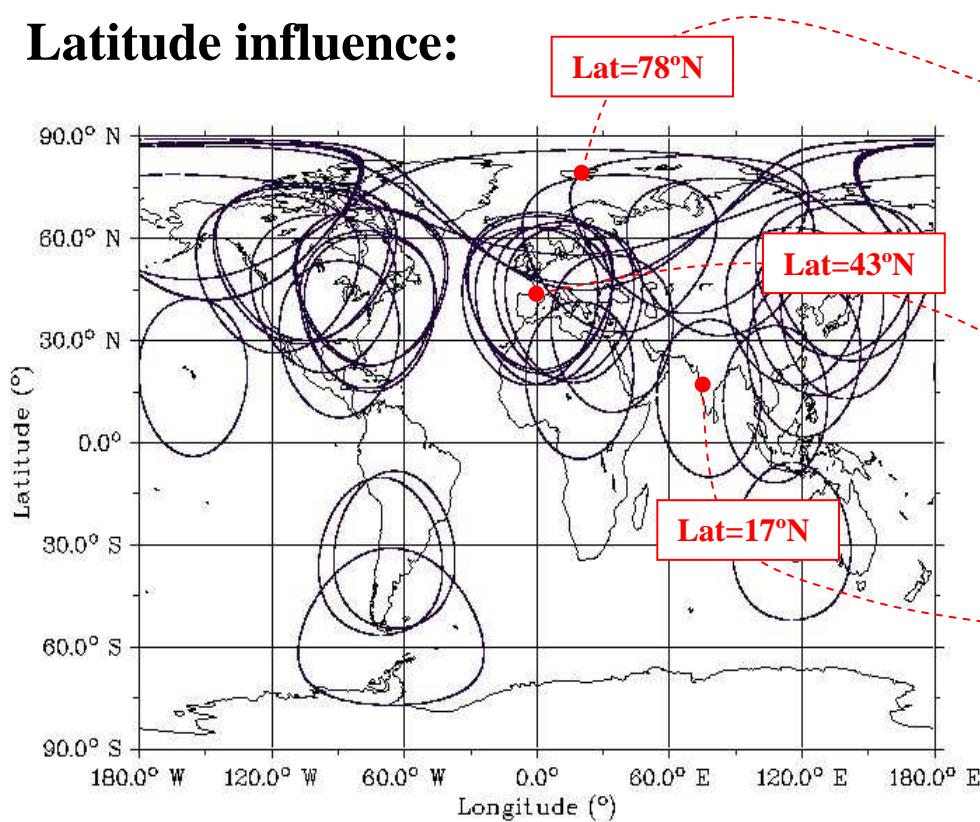
Band occupation is not uniform



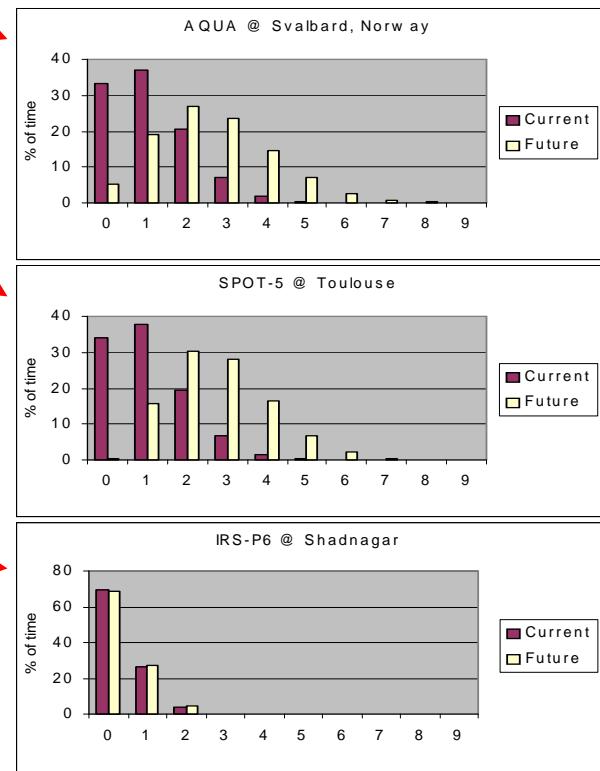
Simulation results

Impact of the latitude of the Earth Station

Latitude influence:



Number of interfering satellites distribution:

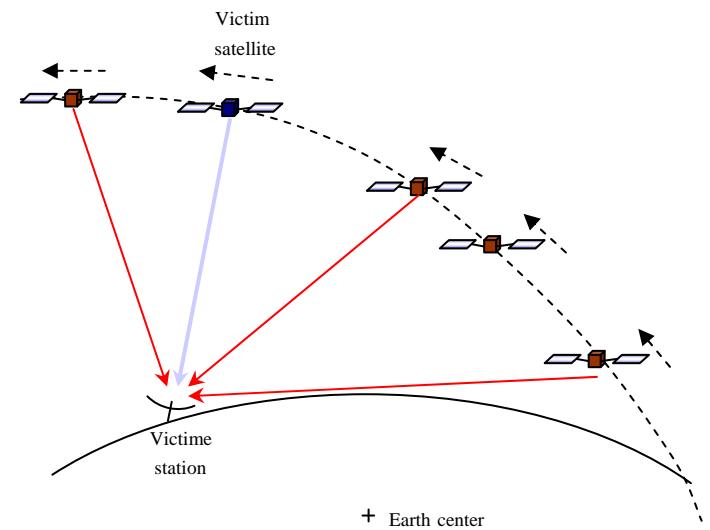
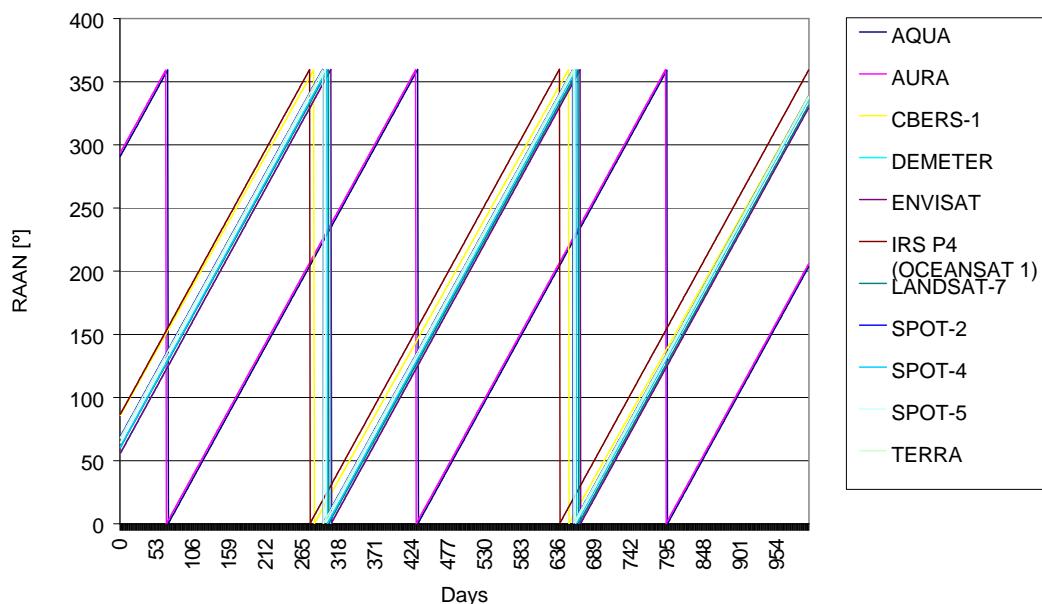


Simulation results

Phased orbits

Many missions are sun-synchronous and therefore have similar values of Right Ascension of the Ascending Node

⇒ satellites close to each other

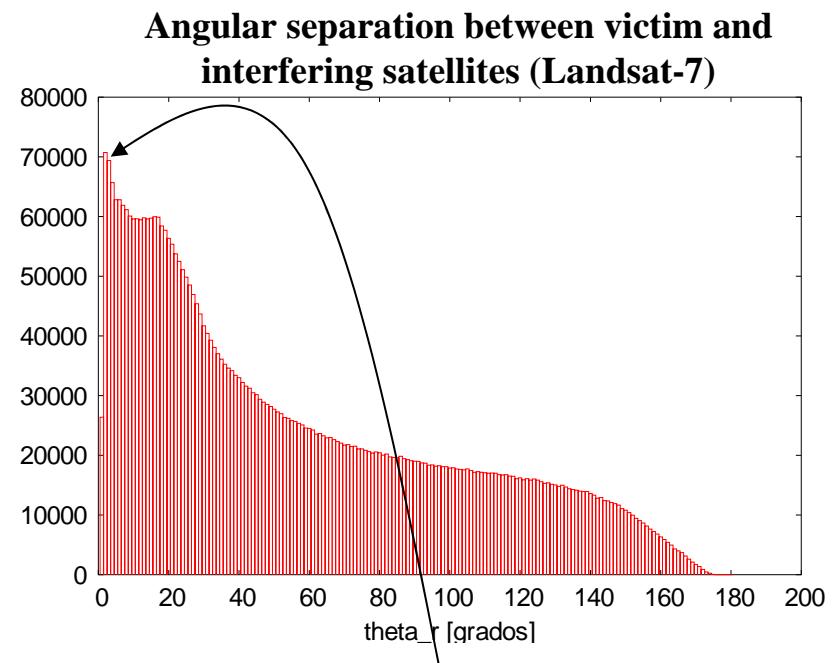
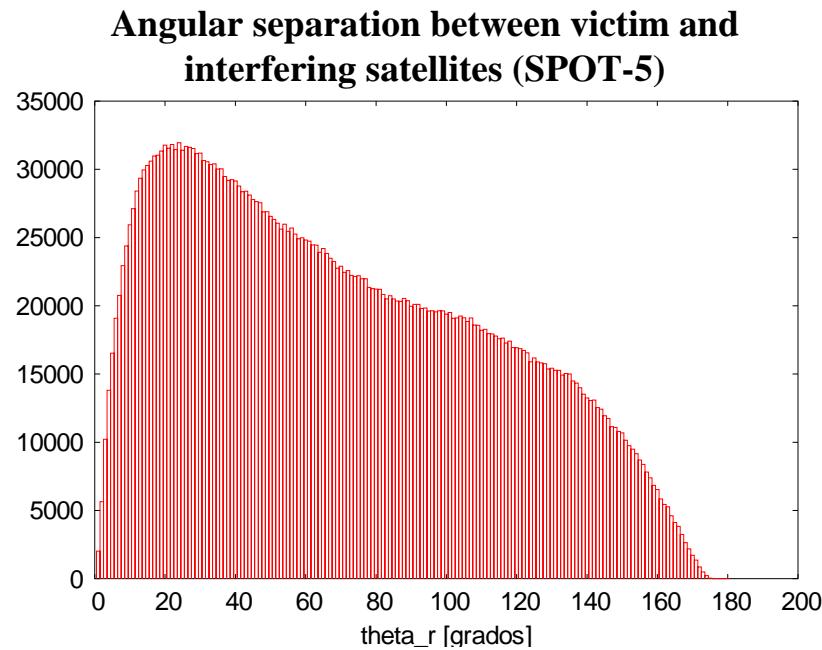


Radar: 5h00 - 8h00
Optic: 10h00 – 14h00

Simulation results

Phased orbits

Satellite have different altitudes \Rightarrow angular separation with other space vehicles fluctuates



Simulation results

Current and future interference power density

- Latitude →
- + SAC-C @ Falda del carmen
 - + IRS-P6 @ Shadnagar
 - + SPOT @ Toulouse
 - + Lansat-7 @ Sioux Falls
 - + Radarsat @ Gatineau
 - + IRS-P6 @ Neustrelitz
 - + Quickbird-2 @ Fairbanks
 - + Aqua @ Poker Flat
 - + Icesat @ Poker Flat
 - + Aqua @ Svalbard

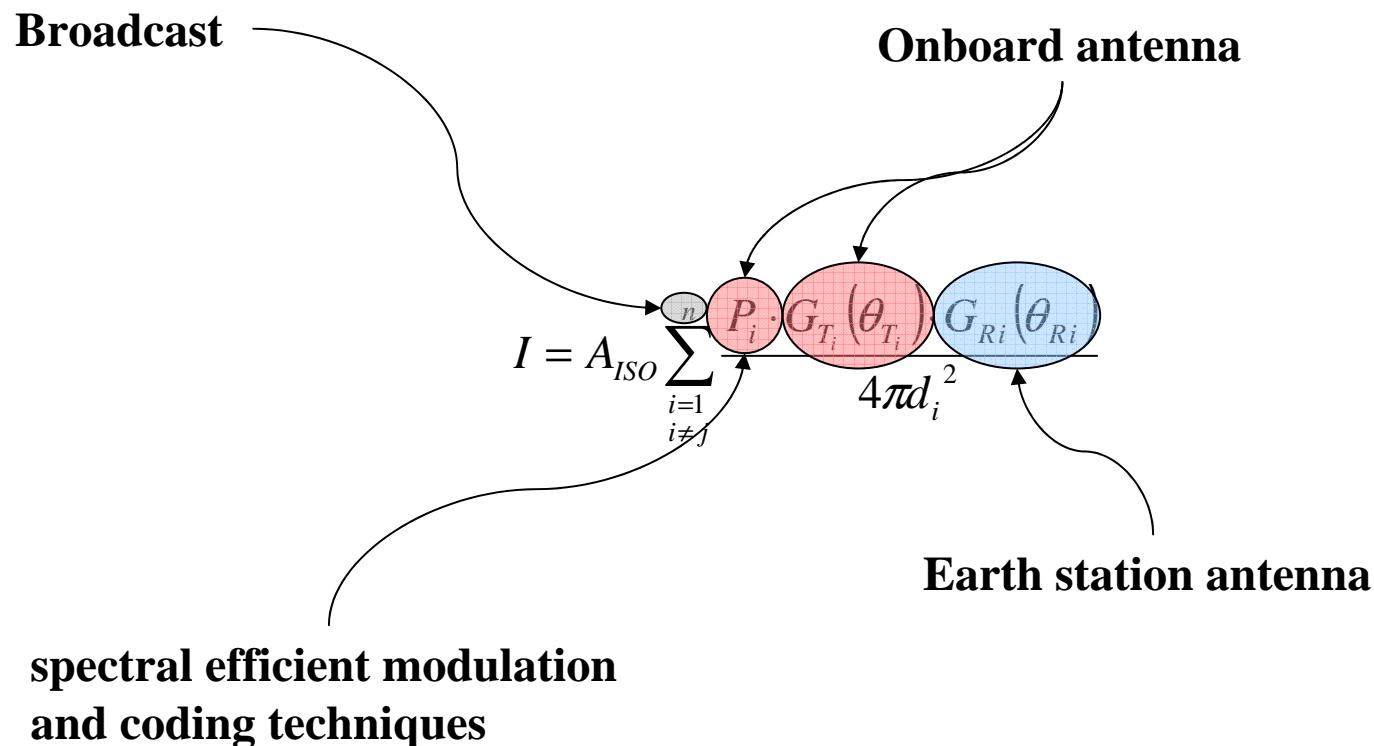
I0 (0.025%)	-197 dBW/Hz
I0 (0.25%)	-201 dBW/Hz
I0 (20%)	-207 dBW/Hz

IRS-P6 @ Neustrelitz			
	Current	Future	Increase
I0 (0,025%)	-198,74	-198,66	1,86%
I0 (0,25%)	-213,36	-213,31	1,16%
I0 (20%)	-241,00	-240,84	3,75%
SAC-C @ Falda del carmen			
	Current	Future	Increase
I0 (0,025%)	outre 246,50 MHz	244,8853 MHz	-1,68%
I0 (0,25%)	246,45	249,77	1,35%
I0 (20%)	-204,88	-204,76	2,80%
I0 (0,25%)	-218,27	-217,81	11,17%
I0 (20%)	-241,40	-240,20	31,83%

Simulation results

How to mitigate and to limit the interference ?

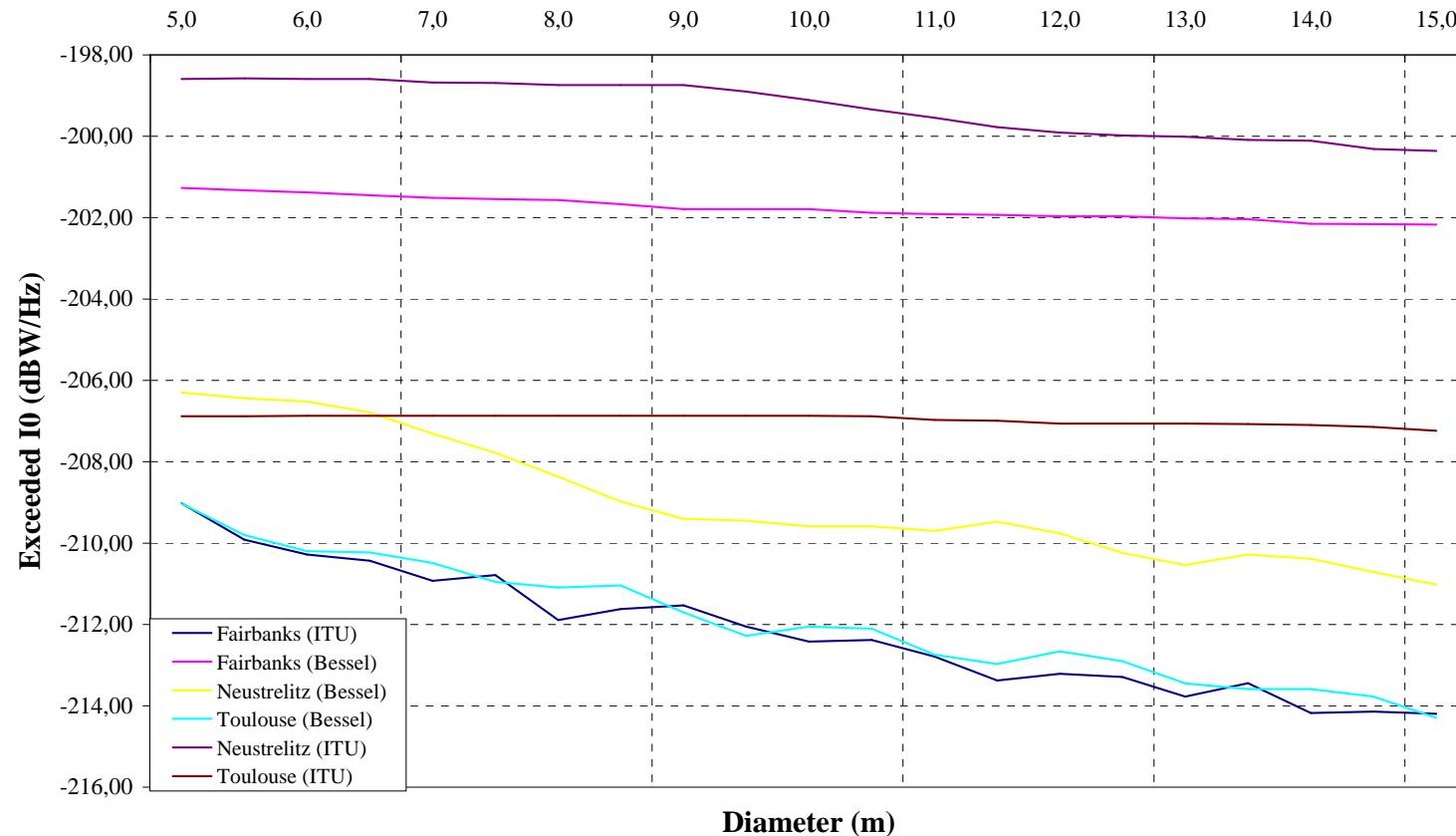
Several parameters can be optimized :



Simulation results

Earth station antenna :

Impact of the antenna diameter on the I0 exceeded during 0.01 % of time



Simulation results

On-board antenna :

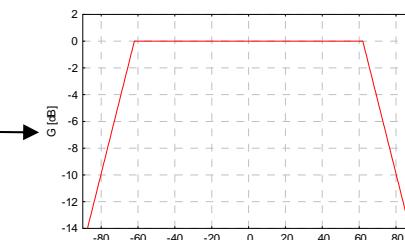
- SAC-C @ Falda del carmen
- IRS-P6 @ Shadnagar
- SPOT @ Toulouse
- + Lansat-7 @ Sioux Falls
- + Radarsat @ Gatineau
- + IRS-P6 @ Neustrelitz
- + Quickbird-2 @ Fairbanks
- + Aqua @ Poker Flat
- + Icesat @ Poker Flat
- + Aqua @ Svalbard

Latitude

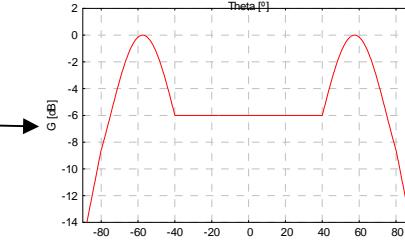
+



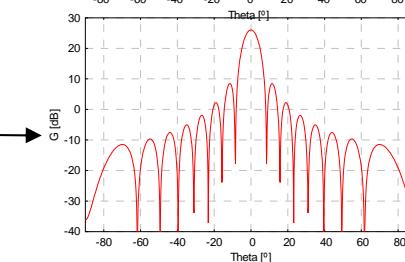
Isogain



Isoflux



Directive



Simulation results

On-board antenna (mid-latitude) :

✚ Lansat-7 @ Sioux Falls

	Future	Isogain	Incr	Isoflux	Incr	Directive	Incr
I0 (0,025%)	-207,10	-206,93	3,99%	-207,10	0,00%	-207,10	0,00%
I0 (0,25%)	-219,80	-219,55	5,93%	-219,81	-0,23%	-219,82	-0,46%
I0 (20%)	-241,36	-241,35	0,23%	-241,36	0,00%	-241,37	-0,23%

✚ Radarsat @ Gatineau

	Future	Isogain	Incr	Isoflux	Incr	Directive	Incr
I0 (0,025%)	-212,99	-212,98	0,23%	-212,99	0,00%	-213,05	-1,37%
I0 (0,25%)	-225,78	-225,75	0,69%	-225,78	0,00%	-225,78	0,00%
I0 (20%)	-257,48	-256,71	19,40%	-257,72	-5,38%	-257,72	-5,38%

✚ IRS-P6 @ Neustrelitz

	Future	Isogain	Incr	Isoflux	Incr	Directive	Incr
I0 (0,025%)	-198,66	-198,61	1,16%	-198,66	0,00%	-198,74	-1,83%
I0 (0,25%)	-213,31	-213,29	0,46%	-213,31	0,00%	-213,36	-1,14%
I0 (20%)	-240,84	-240,79	1,16%	-240,84	0,00%	-241,00	-3,62%

Simulation results

On-board antenna (high-latitude) :

✚ Quickbird-2 @ Fairbanks

	Future	Isogain	Incr	Isoflux	Incr	Directive	Incr
I0 (0,025%)	-199,39	-199,28	2,57%	-199,43	-0,92%	-199,39	0,00%
I0 (0,25%)	-212,15	-212,09	1,39%	-212,20	-1,14%	-212,17	-0,46%
I0 (20%)	-236,72	-236,64	1,86%	-236,94	-4,94%	-236,75	-0,69%

✚ Aqua @ Poker Flat

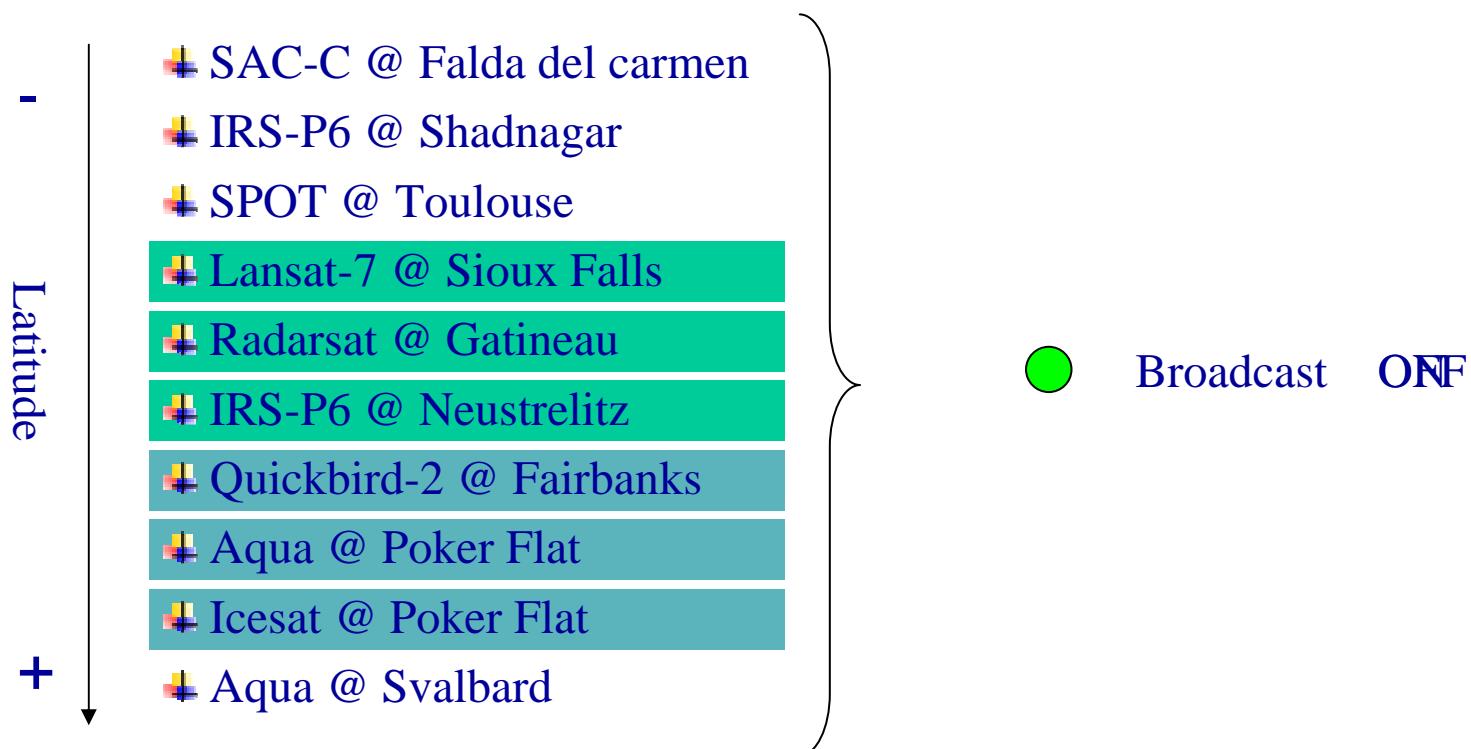
	Future	Isogain	Incr	Isoflux	Incr	Directive	Incr
I0 (0,025%)	-207,49	-207,58	-2,05%	-207,66	-3,84%	-207,38	2,57%
I0 (0,25%)	-220,29	-220,33	-0,92%	-220,44	-3,39%	-220,10	4,47%
I0 (20%)	-247,94	-247,54	9,65%	-248,00	-1,37%	-247,78	3,75%

✚ Icesat @ Poker Flat

	Future	Isogain	Incr	Isoflux	Incr	Directive	Incr
I0 (0,025%)	-204,22	-204,26	-0,92%	-204,31	-2,05%	-204,17	1,16%
I0 (0,25%)	-217,03	-216,99	0,93%	-217,11	-1,83%	-216,96	1,62%
I0 (20%)	-242,99	-242,65	8,14%	-243,15	-3,62%	-242,82	3,99%

Simulation results

Use of broadcast modes



Simulation results

Use of broadcast modes

Middle latitude:

Lansat-7 @ Sioux Falls

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-18.72%	-38.76%	-29.69%

Radarsat @ Gatineau

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-28.71%	-0.46	-0.00%

IRS-P6 @ Neustrelitz

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-0.00%	-0.00%	-0.00%

High latitude:

Quickbird-2 @ Fairbanks

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-9.22%	-11.90%	-11.08%

Aqua @ Poker Flat

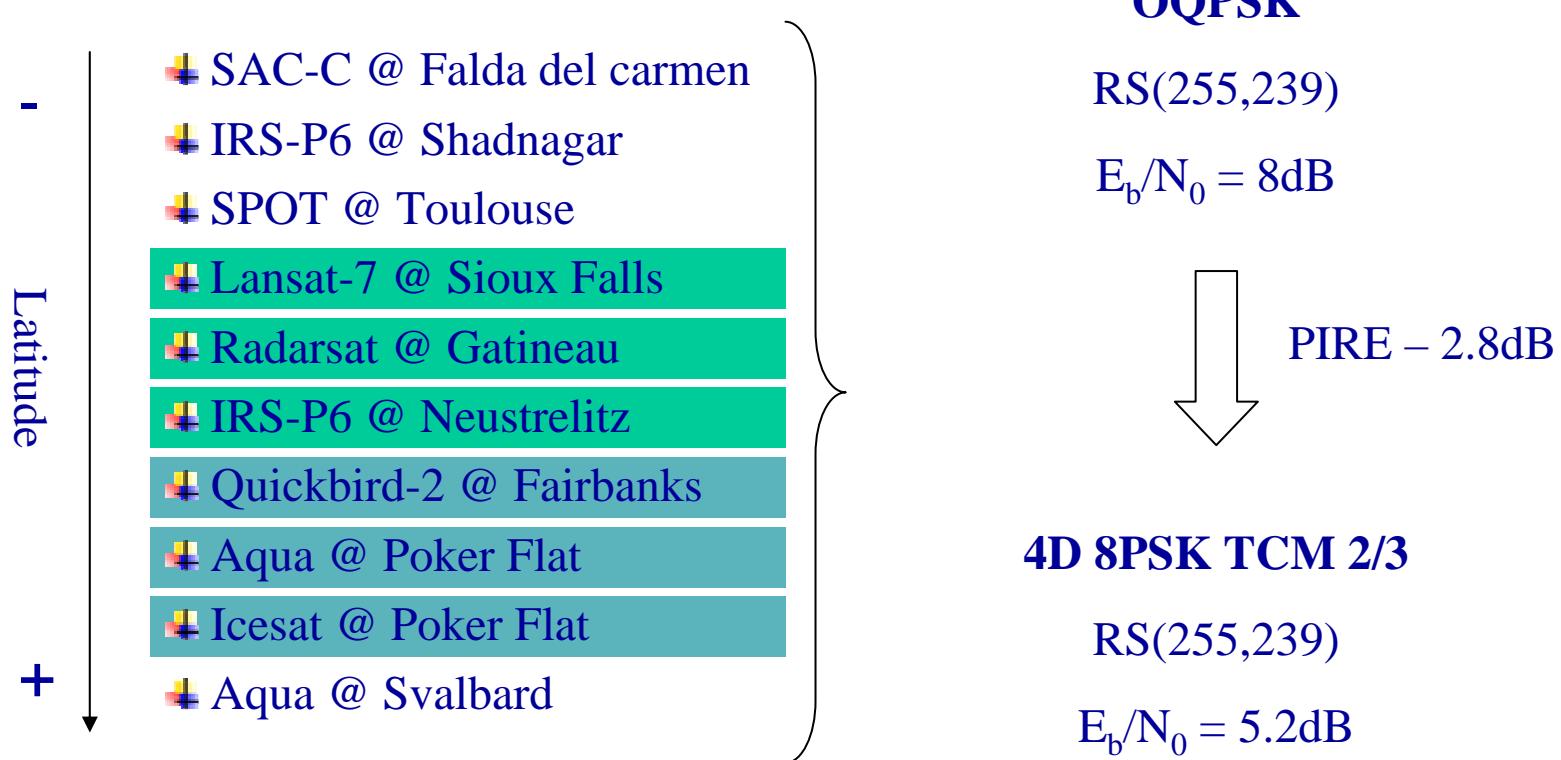
I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-6.24%	-0.46%	-0.46%

Icesat @ Poker Flat

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-32.70%	-16.63%	-15.08%

Simulation results

Use of bandwidth efficient modulation



Simulation results

Use of bandwidth efficient modulation

Middle latitude:

Lansat-7 @ Sioux Falls

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-5.81%	-16.44%	-13.50%

Radarsat @ Gatineau

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-17.96%	-0.46%	0.00%

IRS-P6 @ Neustrelitz

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-1.60%	-0.69%	-0.69%

High latitude:

Quickbird-2 @ Fairbanks

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-20.75%	-16.25%	-16.63%

Aqua @ Poker Flat

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-19.65%	-29.04%	-27.39%

Icesat @ Poker Flat

I0 (20 %)	I0 (0.25 %)	I0 (0.025 %)
-30.18%	-25.70%	-27.22%



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Conclusion

A complete data base has been setup :

- ⇒ SFCG data base (RF characteristics and orbital parameters for future missions)
- ⇒ NORAD data base (orbital parameters for in-orbit missions)

Interference risks seem to be low today :

- ⇒ But ITU criteria may not be enough restrictive
- ⇒ Interference levels will increase from 50 to 200 % in the next decade

Regulate and optimize the use of the X-Band :

- ⇒ ITU Recommendations (ITU-R SA 1026-3...)
- ⇒ SFCG Recommendations (21-2R2, 21-3R1, 18-2, 14-3R6 prov)
- ⇒ CCSDS Recommendations (2-4-18....)